FRACTURE STUDY OF HUMAN BONES BY OPTICAL METHODS

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An experimental method based on birefringent coatings and caustics is proposed to determine stress intensity factors in human precracked femur specimens. The experimental results are in close agreement with the theoretical predictions. The methodology developed is relevant for application to opaque materials that either cannot provide surfaces of high reflectivity or polishing their surface is a laborious and time-consuming task.

INTRODUCTION

Characterization of fracture of bones within the frame of fracture mechanics necessitates experimental determination of fracture toughness expressed by the critical value of stress intensity factor. Pioneering works in the area of fracture mechanics of bone are given in references (1)-(9). The optical method of caustics has extensively been used for the experimental determination of stress intensity factors in transparent and opaque materials (10,11). However, direct application of the method to bones is not possible since bone has a porous surface that cannot provide high reflectivity as it is required in the method of caustics. It is the objective of this communication to develop a new method based on the method of caustics in conjunction with the method of birefringent coatings for the evaluation of stress intensity factors in human bones.

THE METHOD

According to the proposed method a thin layer of a transparent material referred to in the sequel as coating is bonded on the surface of the human cortical bone. When the home is stressed and the coating is perfectly bonded to the surface of the bone,continuity

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conditions of the displacement field are satisfied on the interface and the in-plane displacements of the surface of the bone are transmitted to the coating. Owing to the displacements transmitted to the coating, a state of stress is develop in it. Therefore, differences of the optical-path lengths along the principal stress directions of the coating are induced. When the coating is illuminated by a light beam a caustic is formed on a screen placed at some distance from the plate. This caustic can be used to obtain the stress intensity factor in the body.

The stress intensity factor K_I is given by according to (12)

$$K_I = \frac{0.0939}{2cz_0 d^c m^{3/2}} \frac{E^s(1-v^c)}{E^c(1-v^s)} D^{5/2} \tag{1}$$

where c is the stress-optical constant of the coating, E^c and E^s, and v^c and v^s are the moduli of elasticity and Poisson's ratios of the coating and specimen, respectively, d^c is the thickness of the coating, z_0 is the distance between the specimen and the reference screen where the caustic is formed, m is the magnification factor defined as the ratio of a length on the reference screen and the corresponding length on the specimen and D is the transverse diameter of the caustic at the crack tip.

EXPERIMENTAL

Specimens were obtained from cadaver human femurs that were preserved and kept frozen at -5° C prior to processing. Specimens were degreased locally and dehydrated by using trichloroethane and acetone, respectively. Coupons of dimensions 61.0 x 17.5 x 4.8 mm were cut. A Plexiglas coating of dimensions 25.4 x 14.3 x 1.0 mm was bonded to the specimens. An edge crack of 7.1 mm was machined through the coating and the specimen. The cortical bone and plexiglas has the following properties as measured from tension tests:

$$E^s = 16.2 \text{ GPa}, \quad v^s = 0.36 \quad \text{(bone)}$$

$$E^s = 2.48 \text{ GPa}, \quad v^s = 0.38, \quad c = 1.65\text{x}10^{-10} \text{ m}^2/\text{N} \quad \text{(Plexiglas)}$$

The specimens were loaded in tension in an Instron machine through adhesively bonded tabs. The experimental arrangement is shown in Figure 1. The specimens were illuminated by a monochromatic light beam emitted from a He-Ne laser. The caustic was taken on a reference screen placed at a distance from the specimen.

In the optical arrangement (Figure 1) the distance between the focal point of the light ray impinging on the specimen and the specimen and the distance between the specimen and the reference screen were changed. Thus, different values of the magnification factor m of the optical arrangement were obtained. The caustics were recorded on the reference screen for different values of the applied load P on the specimen up to P_{max}=554 N.

By measuring the transverse diameter D of the caustic, the value of K_I stress intensity factor was calculated from equation (3).

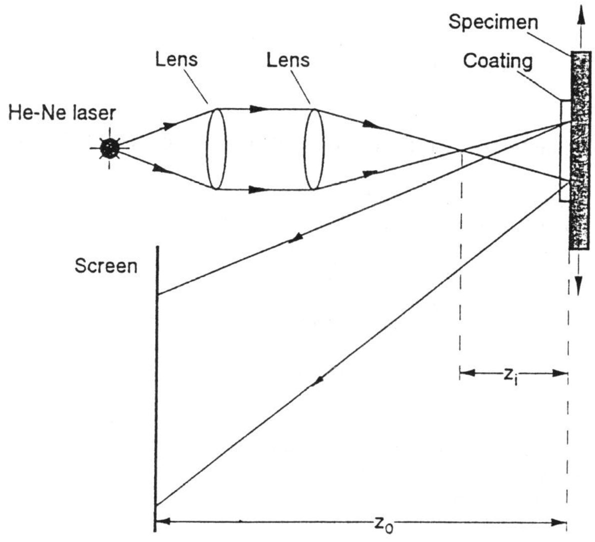

Figure 1 Experimental arrangement.

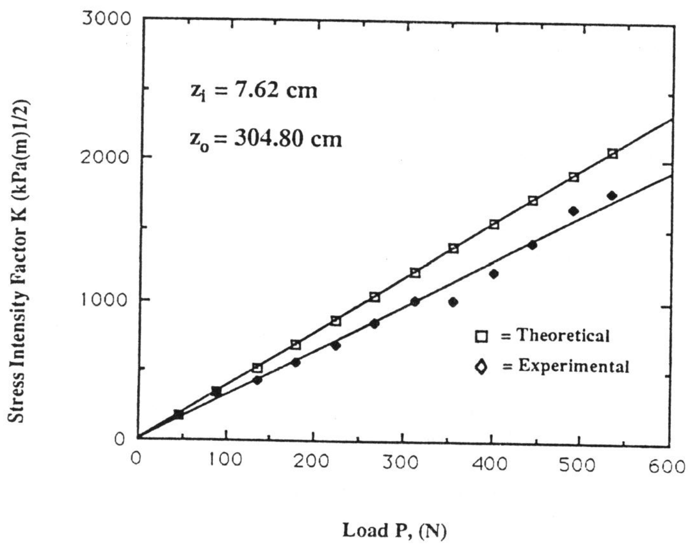

Figure 2 Experimental and theoretical values of stress intensity factor versus applied load for z_i = 7.62 cm and z_0 = 304.80 cm.

For comparison, the theoretical value of K_I was calculated in reference [13] by

$$K_I = \sigma\sqrt{\pi a}\left[1.12 - 0.23\left(\frac{a}{b}\right) + 10.55\left(\frac{a}{b}\right)^2 - 21.72\left(\frac{a}{b}\right)^3 + 30.39\left(\frac{a}{b}\right)^4\right]$$

where σ is the applied stress, a is the crack length and b is the specimen width.

A series of caustics were recorded on the reference screen for various values of the applied load P and the dimensions z_0 and z_i of the optical arrangement. Figure 2 presents the variation of experimental and theoretical values of stress intensity factor versus applied load P up to P_{max}=554 N. The distances z_0 and z_i took the values z_0=304.8 cm and z_i=7.62 cm. From both figures, it can be observed that the experimental values of stress intensity factors are in good agreement with their theoretical values.

CONCLUDING REMARKS

Stress intensity factors in precracked human bone specimens under opening-mode loading were determined by the method of caustics in conjunction with the method of birefringent coatings. The experimental results were in close agreement with the theoretical values. The methodology used is relevant for application to opaque materials that either cannot provide surfaces of high reflectivity or polishing their surface is a laborious and time-consuming task.

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